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Geoinformation Research Directions

     

Ioannis Giannopoulos, Gerhard Navratil, Paolo Fogliaroni, Simge Özdal-Oktay, Marvin Mc Cutchan, Bartosz Mazurkiewicz, Wien

Abstract

This article introduces the research directions of the Geoinformation Research Group at the Vienna University of technology. When we walk in a real or virtual environment as well as when we interact with our surroundings, e. g., buildings, we produce geospatial traces. By analyzing this human generated, but also urban environment data in an efficient and effective way, we are able to answer several research questions of the field. For instance, we can reveal the structure of the environment we live in, investigate the effects of the environment on human decision-making, we can understand how humans interact with the environment as well as enable novel geospatial visualizations and interaction dialogues. Emerging technologies such as virtual and augmented reality as well as eye tracking allow us to go a step further and perform complex experiments in order to generate relevant spatial data that will allow us to investigate and understand the decision making process of humans in controlled environments. Furthermore, due to current technological advances of the Geoinformation Research Group, we can now use the AR technology also in outdoor spaces in order to visualize georeferenced objects in real-time. This provides us the ability to perform experiments also in natural environments, altering the spatial information that the humans can perceive while using our developed technology.

Keywords: Urban Computing, Geospatial Machine Learning, 3D-Cadastre, Outdoor Mixed Reality, Navigation

Kurzfassung

Dieser Artikel stellt die Forschungsrichtungen der Forschungsgruppe Geoinformation an der Technischen Universität Wien vor. Wenn wir uns in einer realen oder virtuellen Umgebung bewegen und mit unserer direkten Umgebung, z. B. Gebäuden, interagieren, produzieren wir raumbezogene Spuren. Durch die effiziente und effektive Analyse dieser vom Menschen erzeugten Daten, aber auch von der städtischen Umwelt, sind wir in der Lage, mehrere Forschungsfragen des Bereichs zu beantworten. Zum Beispiel können wir die Struktur der Umwelt, in der wir leben, aufdecken, die Auswirkungen der Umwelt auf die menschliche Entscheidungsfindung untersuchen, verstehen wie Menschen mit der Umwelt interagieren, sowie neue raumbezogene Visualisierungen und Interaktionsdialoge ermöglichen. Neuartige Technologien wie Virtual and Augmented Reality sowie Eye Tracking befähigen uns, einen Schritt weiter zu gehen und komplexe Experimente durchzuführen, um relevante raumbezogene Daten zu generieren, die es uns ermöglichen, den Entscheidungsprozess des Menschen in kontrollierten Umgebungen zu untersuchen und zu verstehen. Darüber hinaus können wir aufgrund des aktuellen technologischen Fortschritts der Forschungsgruppe für Geoinformation die AR-Technologie nun auch im Außenbereich einsetzen, um georeferenzierte Objekte in Echtzeit zu visualisieren. Dies erlaubt uns, Experimente auch in natürlicher Umgebung durchzuführen und die räumliche Information, die der Mensch mit Hilfe unserer entwickelten Technologie wahrnehmen kann, zu verändern.

Schlüsselwörter: Städtisches Computing, Räumliches maschinelles Lernen, 3D-Kataster, gemischte Realität, Navigation

1. Introduction

The Geoinformation Research Group works at the intersection of Computer Science, Mathematics, Geography as well as Cognitive Sciences. The research focus lies on the development of novel algorithms that enable to deal with geospatial data in an efficient and effective way. These algorithms ultimately advance the state-of-the art computational theories concerned with the wide range of geospatial data and information. The addressed aspects include but are not limited to representation, storage, visualization, analysis, reasoning, semantic, integration, sharing, and prediction.

The research and technological advances of the last years allow us to deal with highly complex problems and pursue research questions that could not be answered in the past. Our work aims at extracting, analyzing and understanding the structure of urban environments by utilizing intelligent algorithms (see Sections 2.1 and 2.5) and further combine this knowledge with human mobility patterns and geospatial semantics in order to develop prediction models (see Sections 2.2 and 2.3) or even generate collective spatial solutions based on artificial intelligence methods (see Section 2.4).

An additional focus of our work is on user centric aspects, investigating how humans interact with their surrounding environment as well as with spatial information communicated through a digital device. For our research in this domain we utilize emerging technologies such as Augmented and Mixed Reality as well as Eye Tracking and perform experiments in order to investigate optimal visualization techniques (see Sections 3.1 and 3.4) and interaction dialogues between the user and the environment (see Sections 3.2, 3.3). Furthermore, we perform several experiments in the area of Navigation since it provides a content and context rich environment that allows us to investigate how humans consume and use spatial information for decision-making (see Section 4).

2. Geographic Information Science

2.1 Urban Computing

Urban Computing is an interdisciplinary research field that concerns the study and application of computing technologies to urban environments. It leverages concepts of ubiquitous computing, geographic information science, data science, cognitive science, and computer science to answer questions related to urban space, to conceive new urban analytical tools, and to provide services for supporting and enhancing urban studies.

In [1] an urban computing framework[1)] has been introduced that provides information about the urban structure of most cities in the world. This framework provides a base for further research which ultimately enables to represent urban structures and their complex nature in a more complete and accurate way. An analysis of the street intersections has been carried out that resulted in a formal definition and categorization of intersections based on the number of their branches and the similarity to the corresponding “regular intersection”. As argued in [1], this new insight on the structure of the street network of a city can serve multiple goals. For example, it can be used in navigation studies and spatial analysis for choosing representative paths in an urban environment. Furthermore, the availability of this data allows for studying the structural similarity of different cities or for comparing and harmonizing spatial studies carried out in multiple areas.

The urban computing framework is designed to be extended with additional information concerning urban structures, such as geospatial semantics as well as different spatial relations, such as topology, orientation, distance and visibility. The framework will be extended with novel data computed from the ones that are already available in the framework. An example is given in [2] where the basic information about intersection classification is used to study and compute the distribution of sequences of intersections of different types. The higher the amount of available information, the more detailed the characterization of the urban structures. This rich source of information can ultimately be used as input for machine learning algorithms (as discussed in more detail in Section 2.3) in order to automatically detect different place classes such as historic or touristic areas, business districts, etc. Furthermore, spatial similarity can be computed, for example, by representing different spatial objects and the relations among them as a graph and by tuning graph isomorphism algorithms. Finally, the availability of formal and structured descriptions of urban environments can be used in the context of simulation and synthetic dataset generation. Indeed, the graph representation of a city can be used as a template to generate similar graphs and, therefore, virtual look-alike cities.

2.2 Human Mobility Patterns

What can human mobility patterns reveal? Currently, one of our latest research projects deals with identifying the familiarity level of pedestrians with their surrounding environment. Through multiple experiments we try to collect data that can be used as input for machine learning in order to classify urban familiarity. In our experiments, pedestrians have to navigate in urban environments they are familiar with, but also in environments they have never been before. A snapshot of the collected spatial data includes the location of the pedestrian, the movement trajectory as well as the head movements. The basic assumption, which we used in order to approach this problem, is that, if a pedestrian is not familiar with the cur-

1) The resulting data is made available at http://intersection.geo.tuwien.ac.at

rent surrounding environment, there is a higher probability that the search behavior will differ compared to pedestrians that are familiar with it. Thus, this different behavior should be reflected in the measured head movements and mobility pattern in general.

2.3 Geospatial Semantics and Machine Learning

Geospatial semantics reflect how humans see the world. A geo-object can be a restaurant, a forest, a bar, a river, etc. These values are referred to as geospatial semantics. Some semantics describe concepts which are more generic than others, such as "restaurant" versus "china restaurant". Geospatial semantics exhibit a geospatial autocorrelation. It might be more likely to find a bar in a city than in the middle of a forest for example. Machine Learning on the other hand aims at determining functional relationships between parameters. It therefore enables to predict phenomena based on a set of given parameters. The Geoinformation Research Group at TU Wien researches how to predict spatial phenomena, such as urban growth or land covers, based on geospatial semantics. Thus, a machine learning algorithm is trained to detect patterns in the spatial distribution and configuration of geospatial semantics and ultimately aims at predicting the urban growth of cities or to classify land covers. This approach presents an alternative to using remotely sensed imagery, which is traditionally used for such prediction tasks, and reveals geospatial semantics as potent geodata source. In order to perform spatial predictions, the data is firstly preprocessed and then passed to the machine learning algorithm. For machine learning a specific type of algorithm is used: Deep Learning. The preprocessing step transforms the geospatial semantics and their geospatial configuration into a matrix. This matrix reflects distances and angles from a given set of locations to geospatial semantics.

Figure 1 illustrates how the geospatial configuration with respect to the geospatial semantics of a single location is presented: distances and angles to geo-objects with specific semantics define the geospatial semantic configuration for a single point (center of the Figure 1).

The Deep Learning algorithm takes this matrix as an input and predicts spatial phenomena for a set of other locations. Specifically the algorithm determines the urban growth or land cover type based on the geospatial semantic configuration

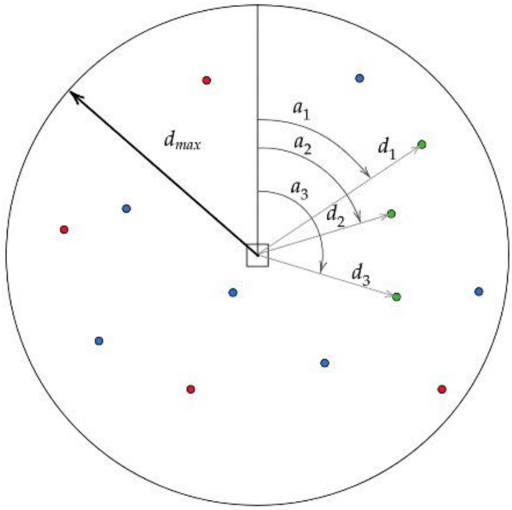

Fig. 1: Geospatial semantic configuration for a single location. This configuration can hold implicit knowledge on the type of land cover the location is in or if it will be subject to urban growth.

[3]. However, other types of spatial phenomena can be predicted as well. Within this scope, we developed one of the most accurate urban growth models. Our results show that predictions can be performed with high overall accuracy as well as high kappa coefficients based on geospatial semantics only. This newly obtained knowledge enables us to understand complex spatial phenomena in a better way and to ultimately model them.

2.4 Qualitative Spatial Reasoning for Collective Plans

Cities are evolving, as complex systems composed of many integrated components. The management and planning of these components requires robust and constantly updated spatial data, local knowledge, as well as the skills to integrate and transmit this information to the planning processes. Therefore, urban planning should refer to an interactive process that involves bilateral information flow and goes beyond the required framework of current applications with a strong focus on the community in order to improve the decision-making process and the final design solutions. In parallel to the increasing mobility, developments in the GIScience field provide an important opportunity for a shift from conventional planning methods to socially inclusive and flexible processes in which users can directly intervene. From the perspective of an experienced urban planner with the main focus of participatory urban design and neighborhood sustainability assessment, the quantitative representation of large amount of qualitative social data is always a requirement to be able to create responsive environments that meet the local needs and priorities and to compare, assess, and monitor the improvements in time. In this scope, there are many recognized methodologies to obtain social data, such as workshops, focus group meetings, gamification, and Web GIS. On the other hand, interpretation of this qualitative data into a collective plan remains a big challenge.

In order to provide a solution to this problem, we developed a geospatial methodology for a collective design solution based on Qualitative Spatial Reasoning (QSR), which is an automated methodology for understanding spatial patterns and spatial relations. Currently, we are conducting experiments in a 3D GIS environment created based on the plan of a courtyard at the Vienna University of Technology. The participants of the experiment can modify the 3D environment based on their individual preferences and with given constraints. In the first phase of the experiment, the user-generated plans were collectively analyzed regarding location, scale, and number of the design elements. The first results of our experiment revealed that the design process helped participants to develop a better understanding of the environment, increase the sense of belonging as well as their acceptance towards a collective plan. Currently, we are applying QSR to each user-generated plan for the computation of the relative location and orientation of the design elements towards each other and within the designated area. This approach provides an efficient methodology to define ontological, topological, and geometrical relationships as well as the spatial patterns in each plan. The overall process will provide an optimal configuration for a collective plan, which will guide designers and urban planners to provide a responsive solution.

2.5 Cadastre

One of the oldest research areas of the Geoinformation Research Group is the cadastre. It started with the implementation of the first curriculum on practical geometry in 1819 [4]. The goal of a cadastre is the creation of land parcel identifiers and the documentation of the land parcel's boundaries and use [5]. The cadastre is closely connected to the land register, the documentation of rights, restrictions, and responsibilities connected to land parcels. In the 200 years of cadastral development in Austria, the system was continuously improved and this process is still ongoing [6].

Our research covers different fields connected to the cadastre and most of them are connected to quality. The simplest case is the quality of existing cadastral maps. Questions like "How to determine quality?" [7], [8] "How to communicate quality?" [9], or "What quality is required?" [10] are essential for the development of applications based on cadastral data. Extensions of the current scope of the cadastre were developed in cooperation with students, e. g., [11] or fellow researchers, e. g., [12]. Finally, connections to the legal domain [4], [13] or design questions [14], [15] were also investigated. Our goal is to provide input for national and international discussions on future cadastral developments.

3. Geographic Human Computer Interaction

3.1 3D Data Visualization

Appropriate visualization is key for making sense of and analyzing data. Specifically, we argue that 3D data can be more easily consumed if presented to the user through a proper 3D visualization. For instance, this can be the case with 3D city models and 3D building models that aim at mapping real spatial objects at different levels of detail. This is also the case of more abstract structures aimed at correlating different primitive concepts in a unified 3D representation, such as space-time cubes: 3D tools for spatio-temporal analysis where the two horizontal dimensions are used to represent the spatial footprint of some phenomenon or object and the vertical dimension is used to denote time.

While it is possible to visualize and interact with 3D data in classical computer environments, this is not optimal as those offer only a 2D representational space and non-natural interactions. That is, the 3D model is to be projected on a 2D plane (the display) and the user can only interact with the object via classical input devices such as mouse and keyboard. As a result, at each point in time the user is presented with a 2D snapshot of the 3D data and she has to move, rotate, and scale the projected model in order to observe the model from different perspectives. After each interaction, the 2D snapshot changes and the user has to mentally stitch those together in order to obtain a complete 3D mental representation of the object.

Conversely, we argue that the cognitive load necessary to create a full 3D mental representa-

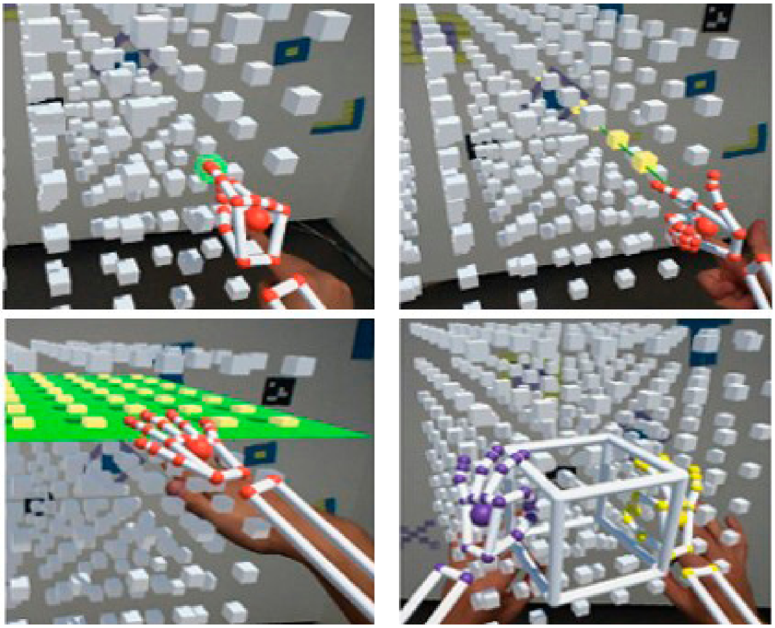

Fig. 2: An implementation of ESRI's space-time cube in a mixed reality environment. The user can perform single-element selection by touching, multi-element selection via predefined gestures and scaling via two-hand pinching.

tion can be significantly reduced by presenting the model in an immersive 3D environment such as a Virtual or Mixed reality environment. Indeed, these environments allow for presenting the model to the user in a much more natural way. The 3D model is presented to the user as if it is a real object embedded in the real space. This allows for leveraging the spatial cognition abilities of the user that does not have to learn and apply artificial mapping techniques to survey and make sense of the model. Finally, interaction modalities can be implemented that resemble and increase the natural interaction capabilities that one has with physical objects. For example, the user can select an element by simply touching it with a finger or can move the object by grabbing or even scale it by stretching or squeezing it in order to obtain a panoramic or detail view.

3.2 Outdoor Mixed Reality

Mixed reality is everything where real and virtual environments (Virtual Reality) are combined [16]. Virtual Reality is an artificial, immersive environment, which the user can interact with. It can be similar to the real world, but does not have to (other definitions of space, time, or physics in general are possible) [16]. Hence, Mixed Reality means either a combination of the real world with virtual objects or a virtual environment enhanced with real world objects. One of our research topics is the use of Augmented Reality (AR) outdoors. AR refers to the real world with virtual objects enhancing (augmenting) it [16].

Augmenting our reality gives us several new possibilities. It is possible to visualize information which otherwise is hidden. The hiddenness of information can be caused, among other things, by physical occlusion (e. g. underground structures like gas or water pipes are occluded by the ground surface) and by its non-physical character (e. g. attributes of physical objects like age). Another application of AR is the inspection if measured entities are placed where they should be (e. g. according to guidelines or a database). This allows an instantaneous correction of both the real world objects' position and virtual objects' attributes. A further use case of AR, not only outdoors, is data collection. The user can immediately create or add data to existing objects. Regarding metadata, this is a big advantage as opposed to adding it later in the office, where memory can fail you or adding metadata based on satellite images, where additional attributes are often not deducible.

While the concept of VR and MR dates back to the 1970's, we are finally witnessing in the last years their actual implementation towards affordable and functional devices. However, these devices and the algorithms they rely upon are mainly conceived for working indoors. One goal of our research group is to investigate and implement the use of MR in outdoor environments (see Figure 3). To this end, it is necessary to merge together indoor and outdoor localization and tracking techniques. In an ongoing project we have implemented a novel approach to create a transformation among the local coordinate system of a MR headset and a geographic reference system. Preliminary experiments were very promising, with a localization accuracy between 2 and 3 cm within

Fig. 3: Both users are interacting with the surrounding environment through a mobile display: on the left side in the form of a tablet and on the right side in form of a glass display (i. e., Microsoft Hololens). We equipped both devices with all the necessary sensors and algorithmic solutions in order to be able to display georeferenced virtual objects in the real environment, thus, enabling outdoor Mixed Reality applications.

the chosen calibration area. Outside of the calibration area, we lose 5 cm of every 10 m of distance from the boundary of the calibration area. Our approach enables users to interact with the surrounding environment in a multitude of ways. In our research we investigate which interaction modalities are better suited for which interaction with the environment. For instance, next to haptic interaction modalities, our focus lies also on gaze-based interaction (e. g. the user can interact with an object by looking at it [17]).

3.3 Gaze-Based Interaction

Our eye movements and where we look at while interacting with spatial elements provide important insights that can help us optimize the (gaze-based) interaction dialogues. In our research we focus on the one hand on eye movements [18] and gaze analysis [19] in order to understand how we interact with our surrounding environment (i. e., real environment, virtual reality and mixed reality) and spatial data visualizations. On the other hand, we utilize the eye movements and the gaze of the user in order to enable novel implicit and explicit interaction dialogues [20]–[23].

3.4 3D-Cadastre

At the end of the 20th century, it became obvious that the traditional cadastral systems have increasing difficulty to cope with the growing density of urban infrastructure (compare [24]). Subways are an example of vertical separation between different types of use. In the last 20 years, airspace above public roads was used for a growing number of development projects and correct documentation of these constructions was problematic at least. In rural areas, it was mainly road and railway tunnels that could not be documented in a legally and graphically convincing way. This resulted in a series of international workshops in the Netherlands, China, United Arab Emirates, and Greece since 2011, supported by a working group of the International Federation of Surveyors (FIG). The Geoinformation Research Group contributed to both, the working group and the workshop series. The discussions include legal (e. g., [25]), technical (e. g., [26], [27]), and usability aspects (e. g., [28]).

Recently, usability aspects of 3D cadastres received more attention than the other aspects. The reason is that the technical questions are discussed extensively in the last 15 years and they are already part of the ISO standard 1952 Land Administration Domain Model (see [29]) and the legal questions will require real cases as further research input. Since there are already several countries with and existing 3D cadastre (e. g., Israel, Sweden, and The Netherlands), such cases should become available. This leaves the problem of usability that has not yet been discussed sufficiently, since it is assumed that 3D CAD solutions will be sufficient for visualization. However, users of a 3D cadastre that are not trained in 3D CAD (e. g., lawyers or politicians) will have difficulties to work with a 3D software. On a 2D map it is simple to indicate a proposed boundary with a

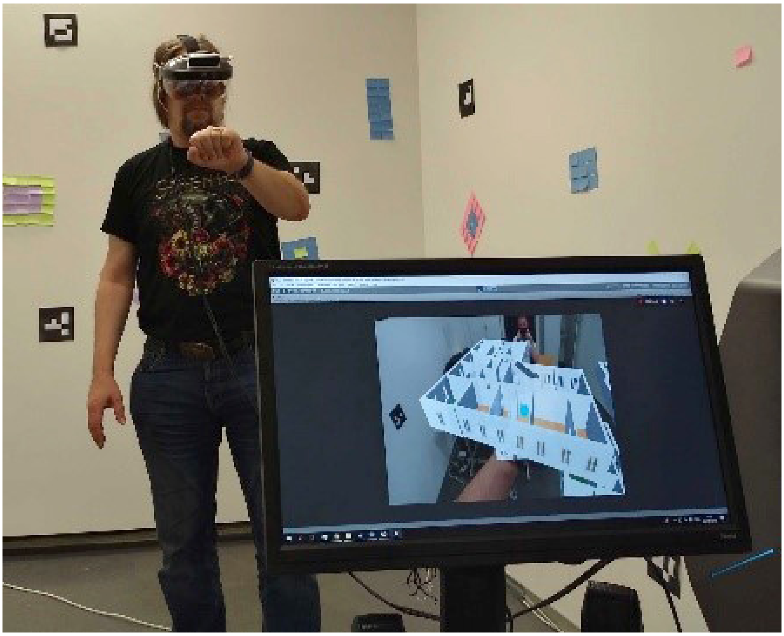

Fig. 4: Working with the first model of an apartment building in mixed reality.

In our work, we perform empirical experiments in order to observe how wayfinders act in real, but also in virtual and mixed environments. These experiments result is multiple spatial data that have to be efficiently analyzed (often in real time) as well as interpreted in order to understand the underlying human processes.

Currently, next to wayfinding assistance systems we are focusing on modeling the complexity of a decision situation [32] as well as on the implementation of a prediction model for optimal timing of pedestrian navigation instructions [33].

pencil line. Our goal is to develop a similarly simple system for 3D models. This requires a simple user interface to work with 3D data in a mixed reality (see Figure 4). First experiments with an apartment building generated promising results regarding user frustration [28].

4. Navigation

According to Montello [30], navigation is composed of two components, locomotion and wayfinding. In our work we focus on the second and most important component, wayfinding. During navigation, we have to make a series of correct spatial decisions in order to reach the desired destination from an origin. Wayfinding can be separated into four processes namely orientation, route planning, route monitoring and recognition of the destination [31]. In most cases during wayfinding we use assistance aids in order to ease the decision-making process, such as cartographic maps or other digital devices such as mobile navigation systems.

The Geoinformation Research Group tries to get insights and unfold the process of wayfinding. We aim at understanding the problems that might occur and at the same time reveal successful strategies that wayfinders use in order to successfully reach their destination.

4.1 Wayfinding Complexity and Assistance

In order to reach a target destination, we have to make a series of wayfinding decisions of varying complexity. Previous research has focused on classifying the complexity of these wayfinding decisions, primarily looking at the complexity of the decision point itself (e. g., the number of possible routes or branches). In our research, we are also incorporating user, instructions, and environmental factors into our modeling process in order to assess the Complexity of a wayfinding decision.

Pedestrian navigation systems help us make a series of decisions that will eventually lead us to the desired destination. Most current pedestrian navigation systems communicate using map-based turn-by turn instructions. This interaction mode suffers from ambiguity, its user's ability to match the instruction with the environment, and it requires a redirection of visual attention from the environment to the screen. In our research, we focus on Navigation Assistance for pedestrian navigation aiming at overcoming these problems and at the same time increase the user experience and decrease the cognitive load.

Assistance systems help wayfinders by providing relevant information within the context of their surroundings, e. g., landmark-based instructions of the type "turn left at the church". Next to the instruction type and content, also the timing of the instruction must be considered in order to facilitate the wayfinding process. In our research we also focus on the user and environmental factors that have an impact on the timing of instructions. We perform experiments in real, but also in realistic virtual environments in order to analyze the expected distance to the decision point until instructions are needed.

The Geoinformation Research Group has opened three research labs (i. e., The VR Lab, The SpatialHCI Lab and The Eye Tracking Lab) in order to investigate all these topics under controlled conditions and in depth. The VR Lab can be used to simulate specific environments as well as specific conditions. For instance, an urban environment can easily be developed and altered to meet the necessary conditions to answer the relevant questions. Furthermore, weather conditions, light conditions as well as pedestrian and automotive traffic can be controlled and manipulated based on user interaction. The SpatialHCI Lab provides us the ability to investigate novel interaction dialogues between a user and the surroundings, e. g., enable interaction modalities that will allow us to interact with a facade of a building, but also with new technologies that can be utilized as assistance systems. Finally, through our research in the Eye Tracking Lab we can collect data that will allow us to investigate the decision making process in depth. Where are humans looking at when making spatial decisions, which environmental aspects are considered important and what strategies can be revealed by analyzing eye movement data.

4.2 Location Based Services

We are constantly interacting with our surrounding environment, either to find our way through the city, to find something we are looking for or just out of curiosity, trying to learn what is around us. Location based services provide us with information and many types of services based on our location. These services, when delivered in an optimal way, i. e., relevance and right amount of information, can be very beneficial for our tasks. In our work, we are focusing on retrieving the right moment to deliver the information/service based on user and environment characteristics as well as on the optimal interaction with the device and environment. For instance, we are focusing on novel interaction dialogues (mostly gaze-based and AR-based) between the user and the surrounding environment [34]. Furthermore, we are aiming at optimizing the amount of information to be delivered based on several user characteristics, such as familiarity with the environment.

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Contacts

Prof. Dr. Ioannis Giannopoulos, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: igiannopoulos@geo.tuwien.ac.at

Dr. Gerhard Navratil, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: gerhard.navratil@geo.tuwien.ac.at

Dr. Paolo Fogliaroni, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: paolo.fogliaroni@geo.tuwien.ac.at

Dr. Simge Özdal-Oktay, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: simge.oktay@geo.tuwien.ac.at

Marvin Mc Cutchan, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: marvin.mccutchan@geo.tuwien.ac.at

Bartosz Mazurkiewicz, Vienna University of Technology, Department of Geodesy and Geoinformation, Research Division Geoinformation, Gußhausstr. 27-29, 1040 Vienna, Austria.
E-Mail: bartosz.mazurkiewicz@geo.tuwien.ac.at

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